



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

Next Generation Nuclear Plant (NGNP)

Office of
Gas Cooled Reactor Technologies
(NE-73)

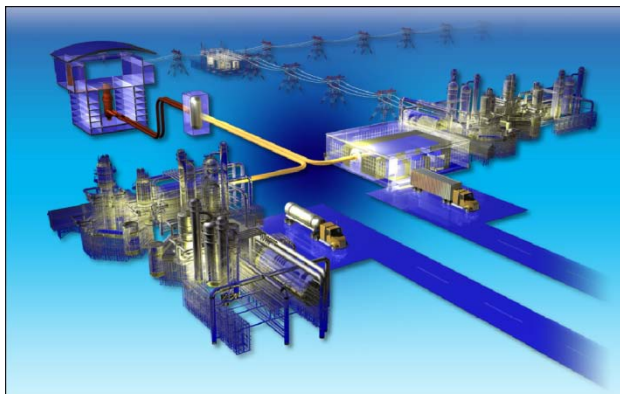
Carl Sink
NGNP Program Manager

March 21, 2012



Mission and Program Objectives

Mission: Demonstrate high-temperature gas-cooled reactor (HTGR) technology to produce electricity and high temperature process heat



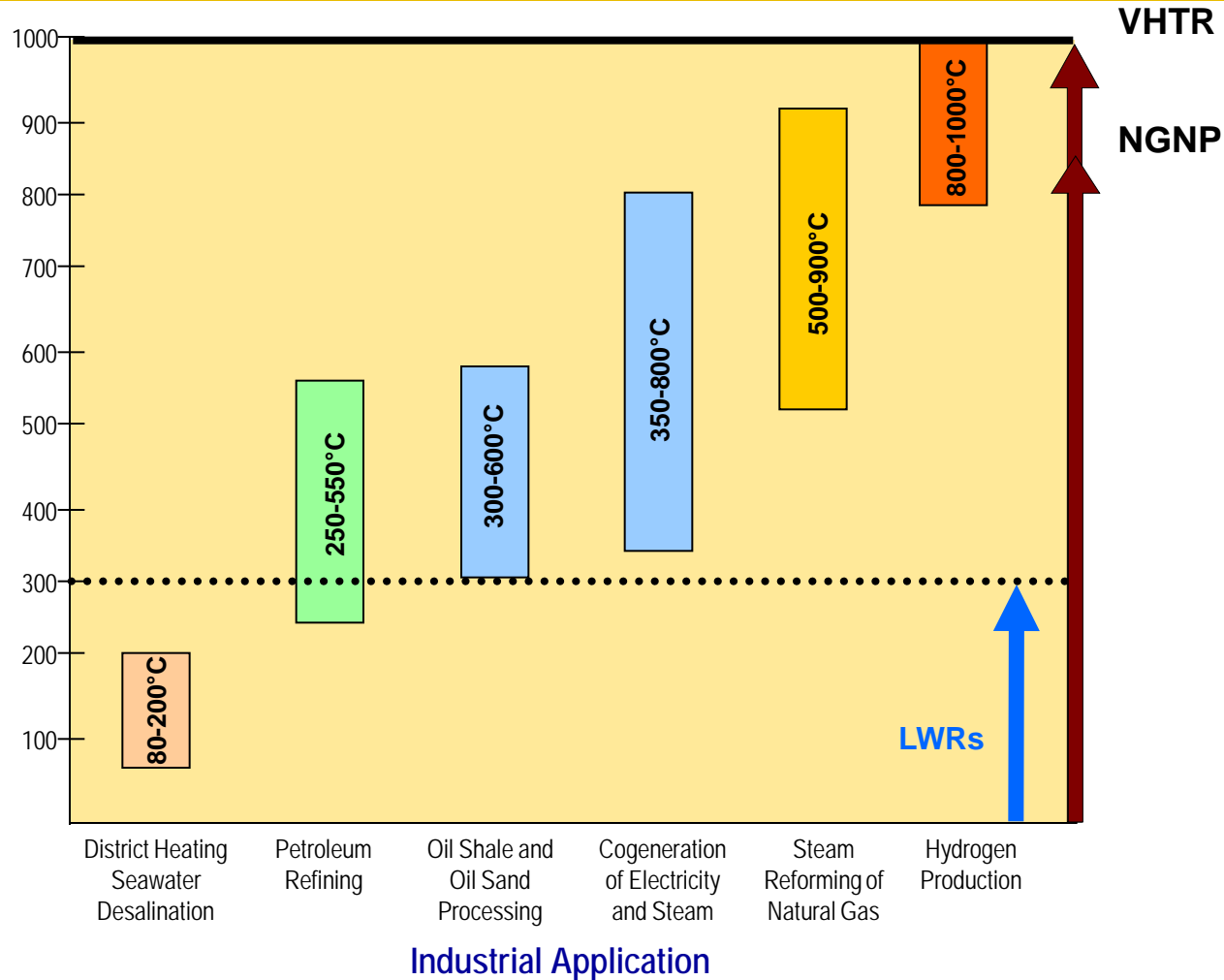
Chronicle / Penni Gladstone

Program Objectives

- Partner with industry to commercialize HTGR technology
- Collaborate with the Nuclear Regulatory Commission (NRC) to establish a licensing framework for HTGRs
- Draw upon the national laboratories, universities, and international community to perform the Research and Development (R&D) necessary to decrease the technical risk



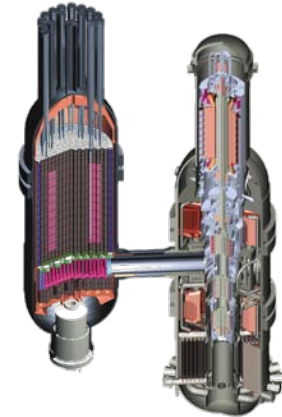
Potential Contribution of Fission Reactors to Process Heat Industries





NGNP – Features and Characteristics

- **Helium cooled** – noble gas does not chemically react
- **High outlet temperature** – 750 °C or greater for high energy conversion efficiency and process heat uses
- **Coated particle fuel** – excellent fission product retention under operating and accident conditions
- **Passive safety features** – ensure public health and safety
- **Small to medium power output** – good fit for industrial applications
- **Improved fuel utilization** – up to three times the burnup of light water reactors



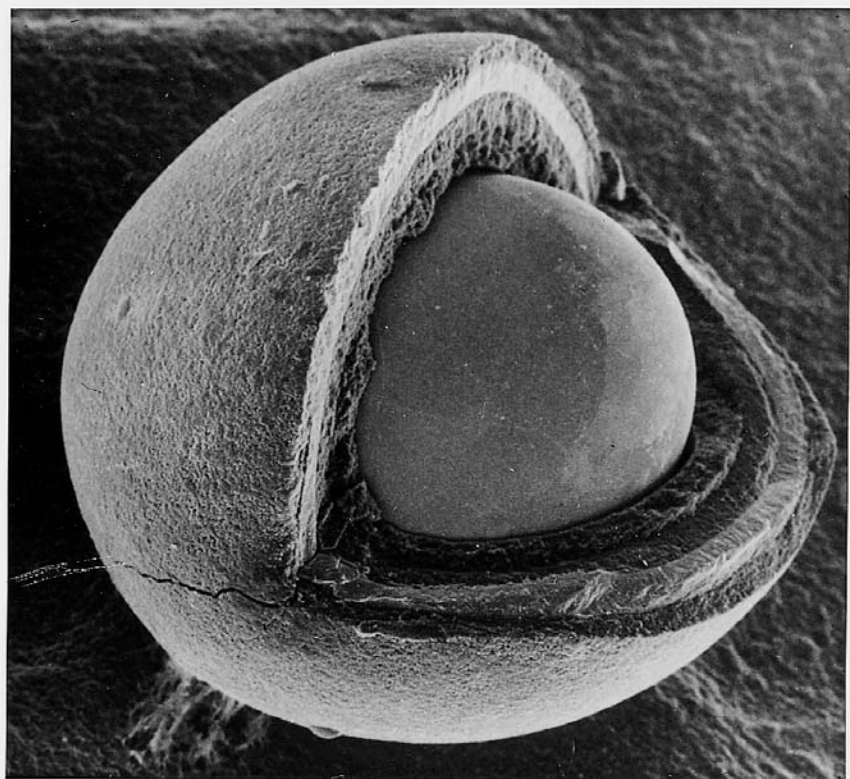


Comparing HTGRs to LWRs

<u>Material</u>	<u>HTGR</u>	<u>LWR</u>
Fuel	UCO, TRISO	UO ₂ Pellets
Fuel clad	PyC/silicon carbide	Zircalloy
Coolant	Helium	Water
Structural material	Graphite	Steel
Moderator	Graphite	Water
Core coolant exit temp.	750°C	310°C
Power density, w/cc	6.6	60
Linear heat rate, kW/ft	1.6	19
Fuel damage temperature	>2000°C	1260°C
Core Structural Damage	>3000°C	1500°C



TRISO Fuel Components / Purpose



Fuel Kernel

Provide fission energy, Retain short-lived fission products

Buffer layer (porous carbon layer)

Attenuate fission recoils, Void volume for fission gases

Inner Pyrocarbon (IPyC)

Provide substrate for SiC during manufacture,
Prevent attack of kernel during manufacture

Silicon Carbide (SiC)

Primary load bearing member, retain gas and metal fission products

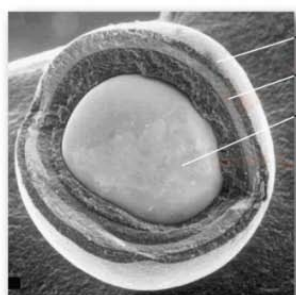
Outer Pyrocarbon (OPyC)

Provide bonding surface for compacting,
Provide fission product barrier in particles with defective SiC

TRISO = Tristructural-isotropic



HTGR Construction



Pyrolytic Carbon
Silicon Carbide
Uranium Dioxide or Oxycarbide Kernel

Prismatic



Particles



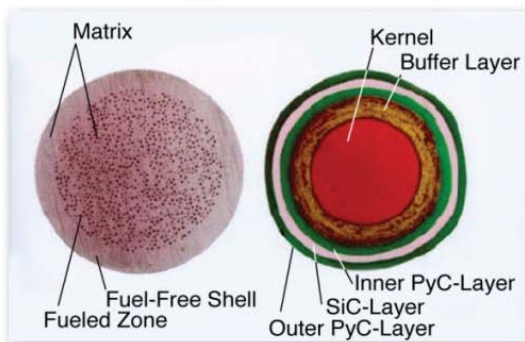
Compacts



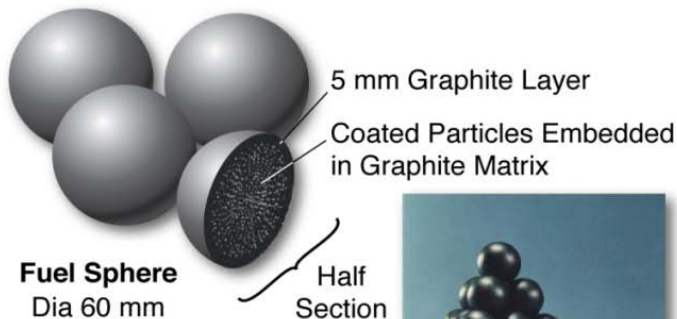
Fuel Element

TRISO-coated fuel particles (left) are formed into fuel compacts (center) and inserted into graphite fuel elements (right) for the prismatic reactor

Pebble



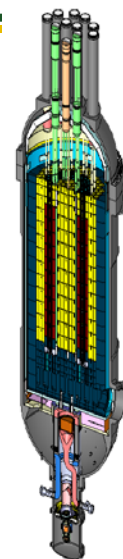
TRISO-coated fuel particles are formed into fuel spheres for pebble bed reactor



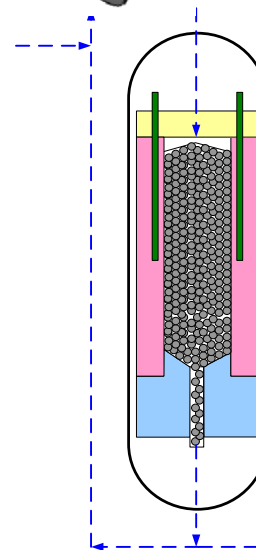
Fuel Sphere
Dia 60 mm



08-GA50711-01



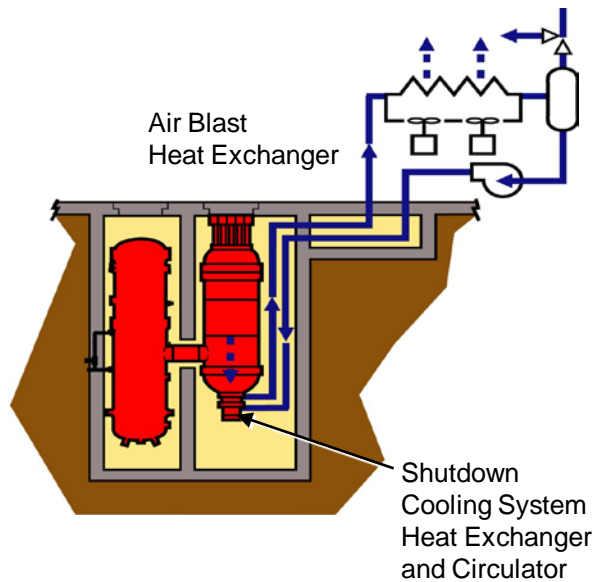
PRISMATIC
CORE



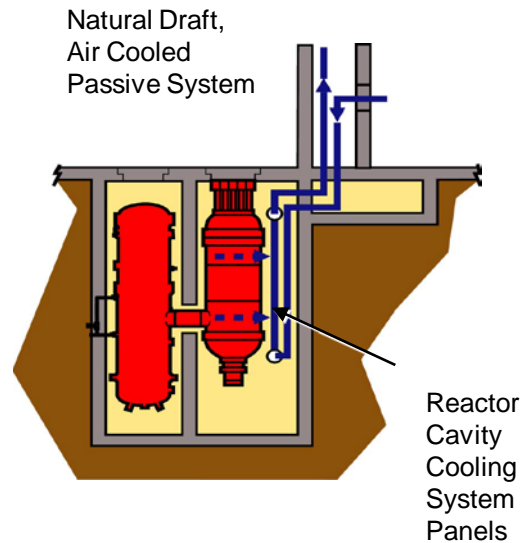
PEBBLE
CORE



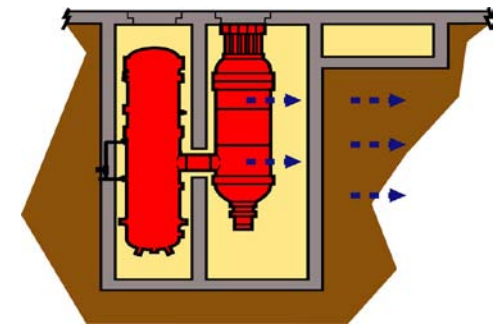
Residual Heat Removal Paths (absent normal forced cooling)



A) Active Shutdown Cooling System



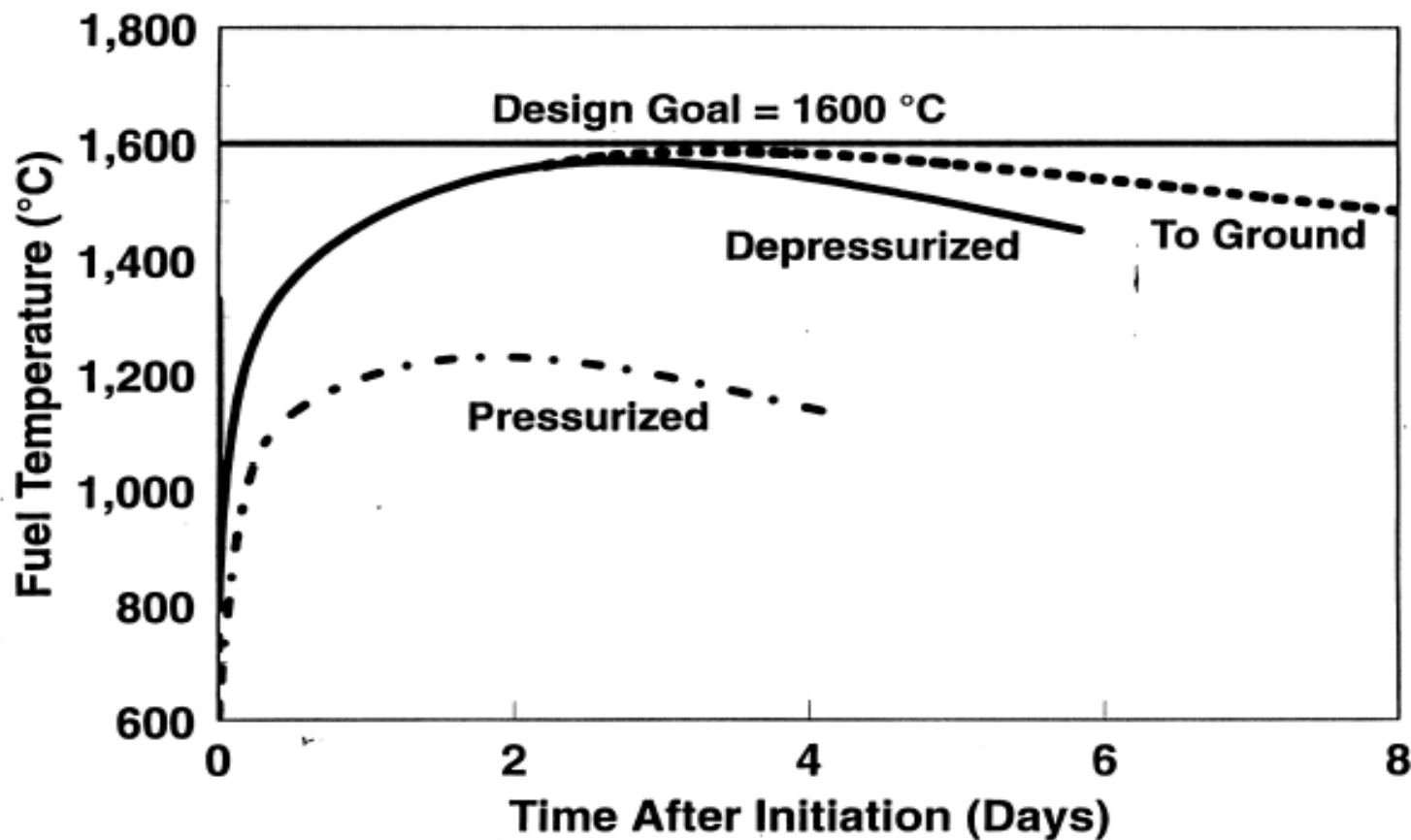
B) Passive Reactor Cavity Cooling System



C) Passive radiation and conduction of residual heat to reactor building (Beyond Design Basis Event)



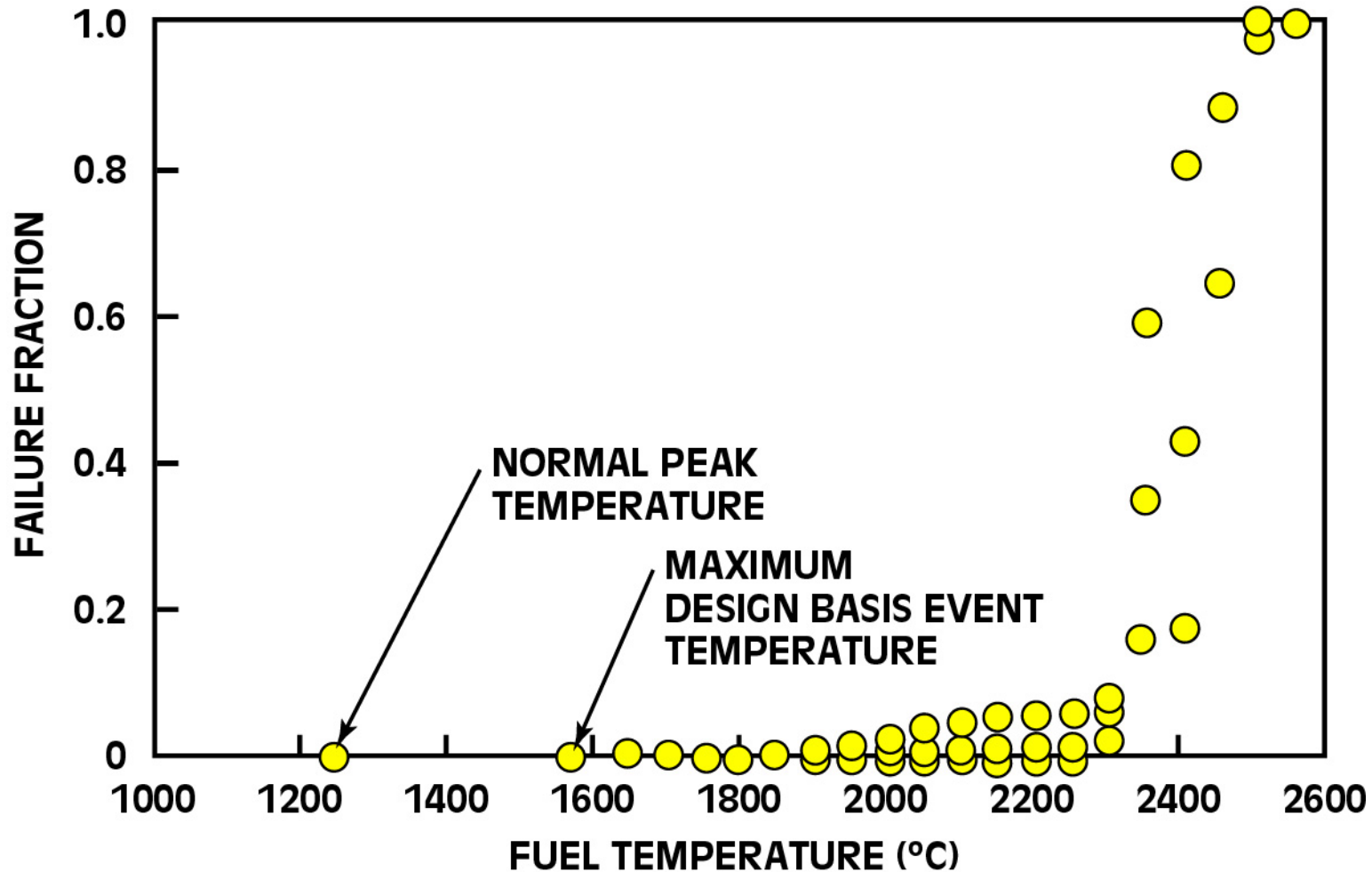
TRISO FUEL TEMPERATURES DURING COOLDOWN EVENTS



Passive design features ensure fuel remains below 1600 C



TRISO Fuel Particle Robustness





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NGNP PROJECT STATUS



NEAC Review of NGNP Phase 1

- **EPAct mandated review by Nuclear Energy Advisory Committee prior to proceeding to Phase 2**
- **NEAC Report forwarded to Congress – October 17, 2011**
- **NEAC Recommendations**
 - Continue Phase 1 R&D
 - Accelerate formation of public-private partnership to obtain end-user input
 - Continue to engage NRC to ensure regulatory framework is in place to support commercialization of this technology
 - Expedite deployment efforts



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NGNP R&D



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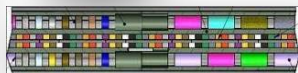
The Nuclear Heat Source Technology Development and Qualification Needs



High Temperature Materials
Characterization, Testing
and Codification



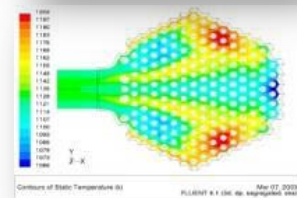
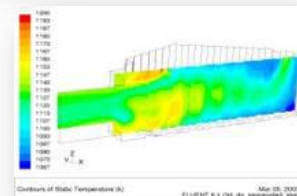
Graphite
Characterization,
Irradiation Testing,
Modeling and
Codification



Fuel Fabrication,
Irradiation, and Safety
Testing

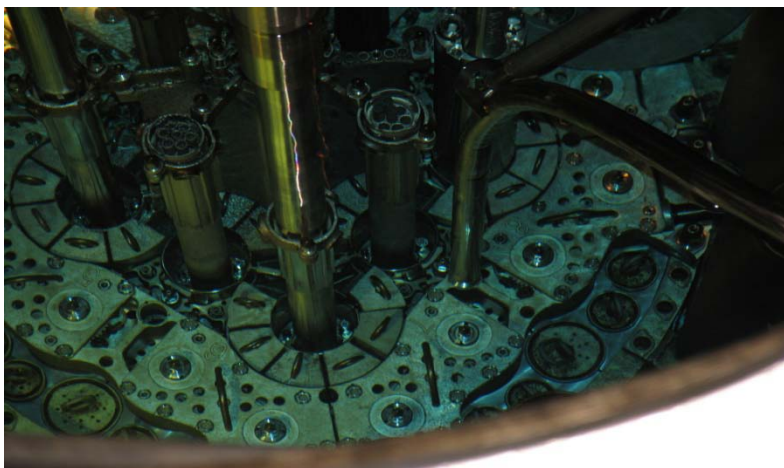


Design and Safety Methods
Development and
Validation





Fuel Qualification Program



■ AGR-1

- Laboratory manufactured fuel
- Completed irradiation and completing PIE

■ AGR-2

- Commercially manufactured fuel
- Includes French and South African fuel
- Irradiation through June 2013

■ AGR-3/4

- “Designed-to-fail” fuel particles
- Irradiation through late 2013



Scaling Up Kernel Production Coating, Overcoating and Compacting Processes to Create a Pilot Line

Lab Scale



Sol-Gel Kernel Production



Lab Scale 2 inch CVD Coating (60 g charge)



Prepare Matrix



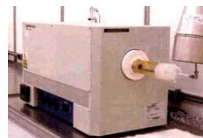
Riffle



Overcoat and Dry



Compact



Carbonize



Sieve



Table



Heat Treat

Industrial Scale



Kernel Forming and Drying



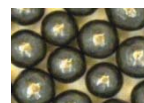
Industrial Scale 6 inch CVD Coating (2 kg charge)



Dry Mix and Jet Mill Matrix



Granurex Overcoat and Dry



Hot Press Compact



Carbonize + Heat Treat in one Sequential Process



Graphite Materials Qualification

■ Baseline measurements program

- “As fabricated” qualities
- Statistical sampling of slab layers

■ AGC-1 through -6

- Irradiation at varying temperatures and dose regimes
- Dimensional, strength and some thermal characteristics change after irradiation
- Capsule simulates in-service loading

■ Oxidation studies

- Engineering and material science issues need resolution
- Air and steam ingress evaluations



■ Creep fatigue experiments at ORNL

- Developing appropriate code cases
- High temperature testing of materials under controlled conditions

■ **Work with ASME:** Metal alloys that can withstand extremely high reactor outlet temperatures

- 800H (iron-nickel-chromium)
- Grade 91 steel (chromium–molybdenum)
- Hastelloy XR (nickel-chromium-iron-molybdenum and N 617).
- Work being carried out by ASME Standards Technology LLC



BPVC Section III-Rules for Construction of Nuclear Facility Components-Division 5-High Temperature Reactors

- All-new; provides construction rules for high-temperature reactors, including both high-temperature, gas-cooled reactors (HTGRs) and liquid-metal reactors (LMRs).
- Meant for components experiencing temperatures that are equal, to or higher than, 370°C) for ferritic materials or 425°C for austenitic stainless steels or high nickel alloys
- Includes new rules pertaining to graphite core components



Design & Safety Methods & Validation





International R&D Collaborations

■ GIF Very High Temperature Reactor System

- Vice-Chair of Steering Committee along with China
- Participation in collaborative research on Fuels, Materials and Hydrogen Production

■ Bilateral Agreements

- Collaboration with Japan (JAEA) for HTTR test data (INL, under development)
- Collaborations with Russia on gas reactors in cooperation (PMDA, and 123)
- Potential bilateral cooperation with China being explored under PUNT

■ International Organizations – IAEA, NEA/OECD



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LICENSING



NGNP Priority Licensing Topics

■ NGNP interactions with NRC are focused on four key areas:

- Event selection process
- Radiological source term
- Containment functional performance and defense in depth
- Emergency planning

■ Related NGNP White Papers submitted to NRC:

- Defense in Depth (Dec 2009)
- Fuel Qualification (July 2010)
- Mechanistic Source Terms (July 2010)
- Licensing Basis Event Selection (Sep 2010)
- Safety Classification of Structures, Systems and Components (Sep 2010)
- Emergency Planning Requirements (Oct 2010)
- Use of PRA, including integrated risk methods (Sep 2011)
- HTGR Safety Basis Overview (Sep 2011)



Licensing Path Forward

- **Engage NRC on disposition of NGNP priority regulatory framework development topics, including common understanding of technology issues**
 - Addressing and resolving open issues from NRC assessment reports
 - Public meetings as needed
 - Continuing R&D collaborations with NRC
- **Continue HTGR Combined License Content Guide development**
 - Assures common applicant and NRC expectations regarding required contents of future license applications
- **Implement an NRC-approved Appendix B Quality Assurance Program**



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SUMMARY



NGNP Path Forward

- **Continue R&D in fuels, materials and code validation experiments**
- **Continue licensing efforts with the NRC**
- **Issue solicitation for development of an economic/business analysis regarding commercializing HTGRs, and providing data and analysis to DOE that could inform DOE on R&D efforts**